UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2010/2011

April/May 2011

ESA 251/3 – Control System Theory
Teori Sistem Kawalan

Duration : 3 hours
Masa : 3 jam

INSTRUCTIONS TO CANDIDATE:
ARAHAN KEPADA CALON:

Please check that this paper contains **SEVENTEEN (17)** printed pages and **FIVE (5)** questions before you begin the examination.
*Sila pastikan bahawa kertas soalan ini mengandungi **TUJUH BELAS (17)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.*

Part A: Answer **ALL** questions. Part B: Answer **TWO (2)** questions.
*Bahagian A: Jawab **SEMUA** soalan. Bahagian B: Jawab **DUA (2)** soalan.*

Appendix/*Lampiran*:

1. Appendix A/ *Lampiran A* [1 page/*mukasurat*]
2. Appendix B/ *Lampiran B* [1 page/*mukasurat*]
3. Appendix C/ *Lampiran C* [1 page/*mukasurat*]

You may answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.
*Calon boleh menjawab semua soalan dalam **Bahasa Malaysia** ATAU **Bahasa Inggeris** ATAU kombinasi kedua-duanya.*

Answer to each question must begin from a new page.
Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru.

In the event of any discrepancies, the English version shall be used.
Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.

PART A/*BAHAGIAN A*

1. The open-loop transfer function of a feedback control system is given as follows:

Rangkap pindah gelung buka satu sistem kawalan suapbalik diberi seperti berikut:

$$G(s)H(s) = \frac{K(s+4)}{(s-1)(s^2+4s+8)}$$

(a) Using the rules for plotting the root locus, sketch the root locus plot on the graph paper provided, as K varies from 0 to infinite.

Dengan menggunakan peraturan binaan londar punca, lakarkan plot londar punca sistem di atas kertas graf yang disediakan, untuk gandaan K *yang berubah dari sifar ke infiniti.*

(For the real axis, use a scale of 1 cm = 0.5 with a maximum value of 4 and a minimum value of –6. For the imaginary axis, use a scale of 1 cm = 0.5 with a maximum value of j7 and a minimum value of –j7).

(Untuk paksi nyata, gunakan skala 1 cm = 0.5 dengan nilai maksimum 4 dan nilai minimum -6. Untuk paksi khayal, gunakan skala 1 cm = 0.5 dengan nilai maksimum j7 dan nilai minimum -j7).

(b) Determine and show on the root locus plot,

Dapatkan dan tunjukkan di atas plot,

(i) the angle of departure from the complex poles.

sudut berlepas londar punca dari kutub kompleks.

(ii) the point of intersection on the imaginary axis and the value of gain K.

titik persilangan londar punca di paksi khayal serta nilai gandaan K.

(c) Determine the range of gain K for the closed-loop system to be stable.
Tentukan julat gandaan K *supaya sistem gelung tutup adalah stabil.*

(25 marks /markah)

2. The open - loop transfer function of a certain unity feedback system is,

Rangkap pindah gelung-buka untuk sistem suapbalik uniti ialah,

$$G(s) = \frac{K}{S(S+2)(S+20)}$$

Construct Bode Plots and determine:-
Bina Plot Bode dan dapatkan:-

(a) gain margin and phase margin if K=40.
jidar gandaan dan jidar fasa jika K=40.

(b) limiting value of K for system to be stable.
nilai penghad K supaya sistem stabil.

(c) value of K for gain margin to be 10 dB.
nilai K untuk jidar fasa 10 dB.

(d) value of K for phase margin to be 50^0
nilai K untuk jidar fasa 50^0

(25 marks/*markah*)

PART B/*BAHAGIAN B*

3. (a) **Figure 3(a)** shows a temperature control system of an electric furnace. The actual temperature in the electric furnace is measured by a thermometer which is an analog device. The analog temperature is converted to a digital temperature by an A/D converter and fed to a computer through an interface. The digital temperature is compared with the input temperature data from the programmed input. If there is any error, the computer sends out an error signal to the heater, through an interface, amplifier and relay, to bring the furnace temperature to the desired value.

Rajah 3(a) *menunjukkan sistem kawalan suhu bagi satu relau elektrik. Suhu relau sebenar diukur menggunakan termometer yang merupakan satu peranti analog. Pengubah A/D menukar suhu analog kepada isyarat digital dan seterusnya dihantarkan kepada komputer melalui satu antaramuka. Suhu digital dibandingkan dengan data suhu masukan dari aturcara masukan. Sekiranya terdapat ralat, komputer menghantarkan isyarat ralat tersebut kepada pemanas melalui antaramuka, penguat dan geganti, supaya suhu relau dikembalikan ke nilai yang diingini.*

(i) Draw a block diagram of the system

Lukiskan gambar rajah blok bagi sistem

(ii) Identify all the components of the block diagram

Kenalpasti semua komponen gambar rajah blok

(iii) State the type of the system

Nyatakan jenis sistem

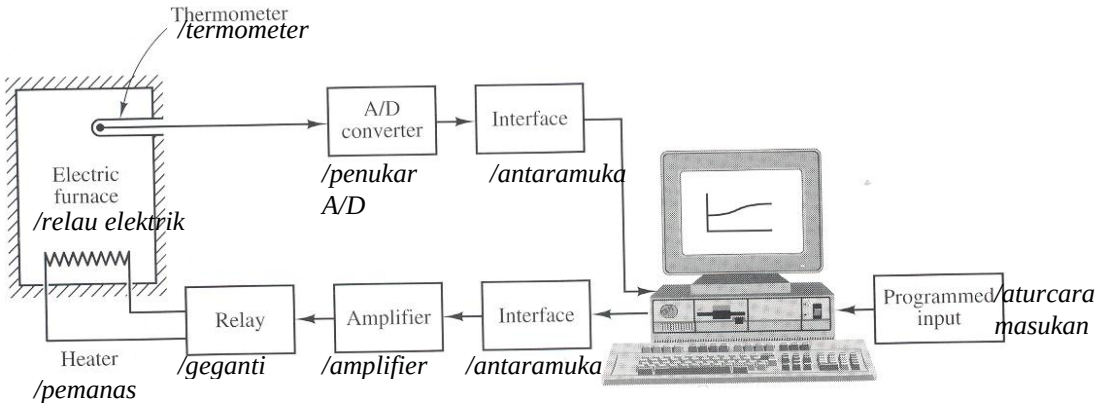


Figure 3(a) /*Rajah 3(a)*

(7 marks/*markah)*

(b) The specifications for a 24V dc motor is given in Appendix A. The dc motor drives a load via a set of gears as shown in **Figure 3(b)**. The load specifications are:

*Spesifikasi untuk satu motor dc 24V diberikan dalam lampiran A. Motor dc ini memandu satu beban melalui sistem gear seperti dalam **Rajah 3(b)**. Spesifikasi beban adalah seperti berikut:*

$N_1 = 16$, $N_2 = 80$

$J_L = 42.5x10^{-4}\ N.m.s^2/rad$ $D_L = 0.02x10^{-4}\ N.m.s/rad$

Neglecting armature inductance,

Dengan mengabaikan induktan angker,

(i) Find the total inertia, J_T, and total damping, D_T, reflected to the motor side.

Dapatkan jumlah inersia, J_T, *dan jumlah redaman,* D_T, *dirujuk kepada bahagian motor.*

(ii) Obtain the Laplace transformed equations for the armature voltage, $E_a(s)$, the back emf voltage, $V_b(s)$, and motor torque, $T(s)$, in terms of the armature current, $I_a(s)$, and motor angular velocity, $\omega_m(s)$.

Dapatkan persamaan jelmaan Laplace untuk voltan angker , $E_a(s)$, *voltan emf balikan,* $V_b(s)$, *dan dayakilas motor,* $T(s)$, *dalam sebutan arus angker,* $I_a(s)$, *dan halaju sudut motor,* $\omega_m(s)$.

(iii) Derive the transfer function relating the motor angular velocity, $\omega_m(s)$, to the armature input voltage, $E_a(s)$. Write the transfer function in the form:

Terbitkan rangkap pindah motor yang menghubungkan halaju sudut motor, $\omega_m(s)$, *kepada voltan masukan angker,* $E_a(s)$. *Tuliskan rangkap pindah dalam bentuk:*

$$\frac{\omega_m(s)}{E_a(s)} = \frac{K}{Ts+1}$$

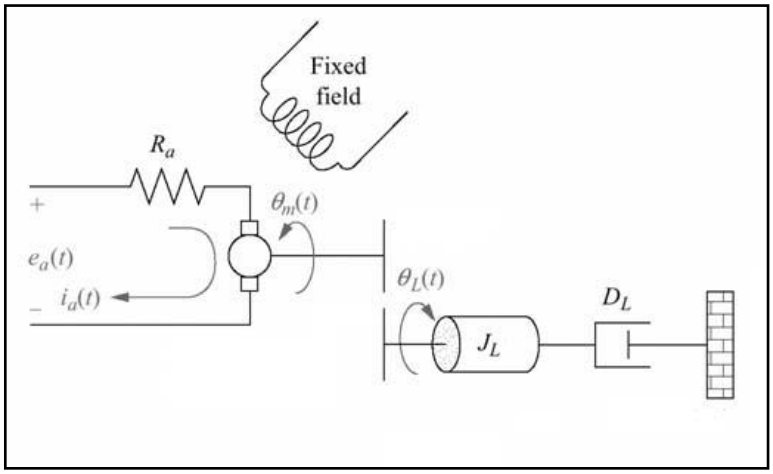


Figure 3(b)/*Rajah 3(b)*

(18 marks/*markah*)

4. **Figure 4** represent the block diagram of a process control system with gain K_P and K_T.

Rajah 4 *mewakili gambar rajah sistem kawalan proses dengan gandaan* K_P *dan* K_T.

(a) Find the system closed loop transfer function.

Dapatkan rangkap pindah gelung tutup sistem.

(b) Given that:
Diberi:

Gain, $K_P = 40$

Gandaan, $K_P = 40$

Steady-state error for a unit ramp input, $e_{ss} = 0.08$

Ralat keadaan mantap terhadap masukan unit tanjakan, $e_{ss} = 0.08$

Determine the required value of:
Dapatkan nilai:

(i) K_T.

(ii) undamped natural frequency, ω_n.
frekuensi tabii tanpa redam, ω_n.

(iii) damping ratio, ζ.

nisbah redaman, ζ.

Using the values of gain K_P and K_T obtained above, calculate the values of:

Menggunakan nilai K_P *dan* K_T *diperolehi di atas, kirakan nilai:*

(iv) percentage of maximum overshoot, $\% c_p$.

peratus lajakan maksimum, $\% c_p$.

(v) settling time, t_s.

masa pengenapan, t_s.

(c) If a unit step input is applied to the system with gain $K_P = 9$ and $K_T = 2$,

Sekiranya sistem dikenakan masukan unit langkah dengan nilai gandaan $K_P = 9$ *dan* $K_T = 2$,

(i) find the output system response and sketch the response.

dapatkan dan lakarkan sambutan keluaran sistem.

(ii) determine whether the following specification can be met. Peak time, $t_p < 0.5$ seconds. Show your workings.

tentukan samada spesifikasi berikut boleh dipenuhi atau tidak. Masa puncak, $t_p < 0.5$ *saat. Tunjukkan jalankerja anda.*

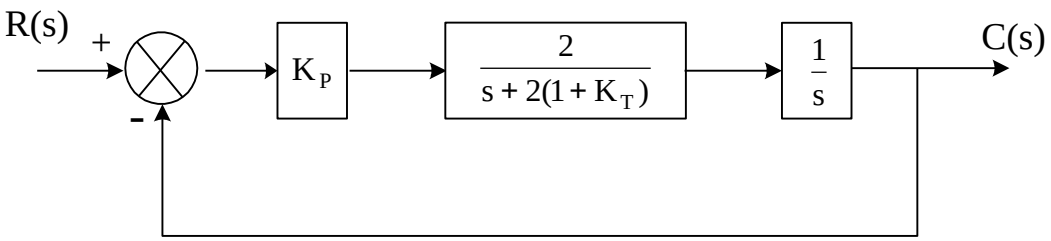


Figure 4/*Rajah 4*

(25 marks/*markah*)

5. (a) Reduce the system described by **Figure 5(a)** to a single block and determine the transfer function of the block.

*Ringkaskan sistem bagi **Rajah 5(a)** kepada blok sistem paling ringkas dan dapatkan rangkap pindah bagi blok sistem tersebut.*

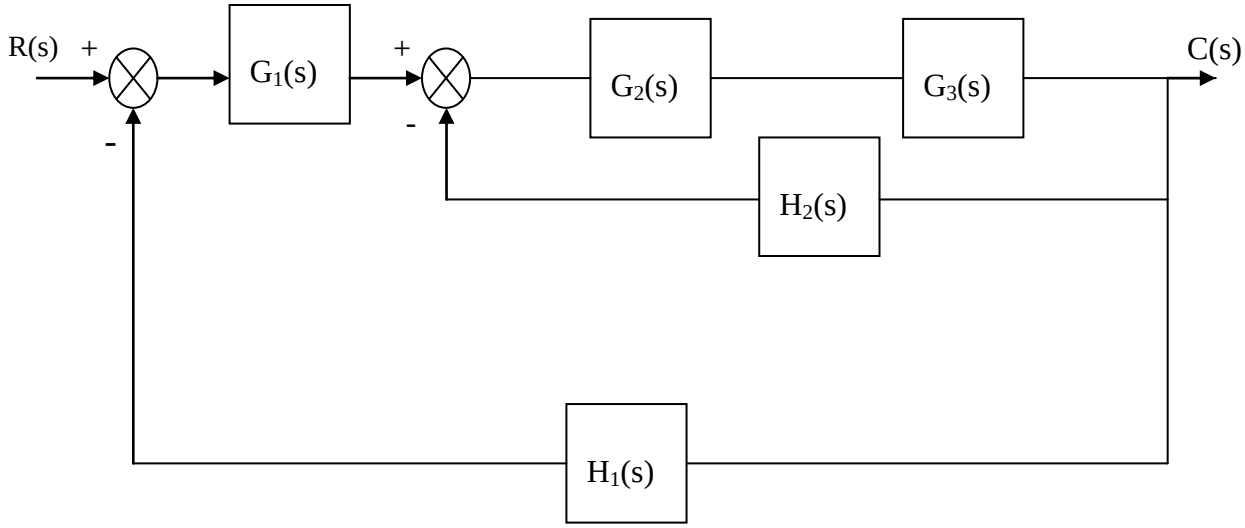


Figure 5(a)/*Rajah 5(a)*

(12 marks/*markah*)

(b) Find the transfer function for the system shown in **Figure 5(b)** by Mason gain formula.

*Dapatkan rangkap pindah bagi sistem dalam **Rajah 5(b)** dengan menggunakan formula Mason.*

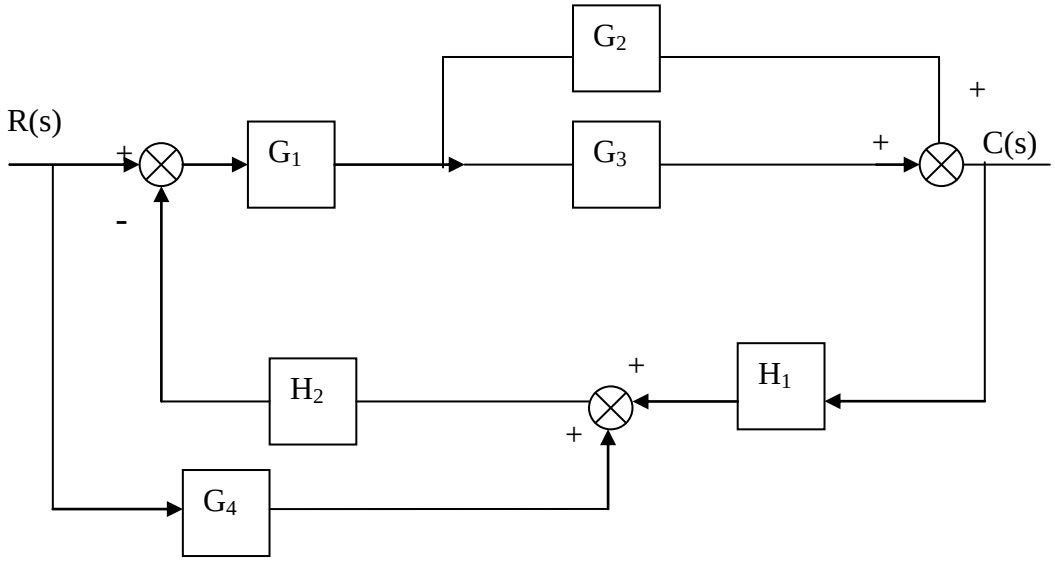


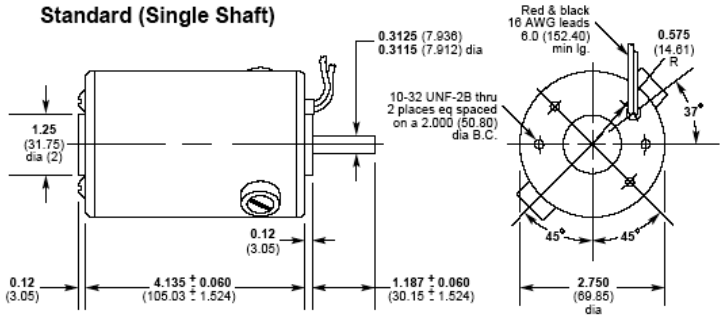
Figure 5(b)/*Rajah 5(b)*

(13 marks/*markah*)

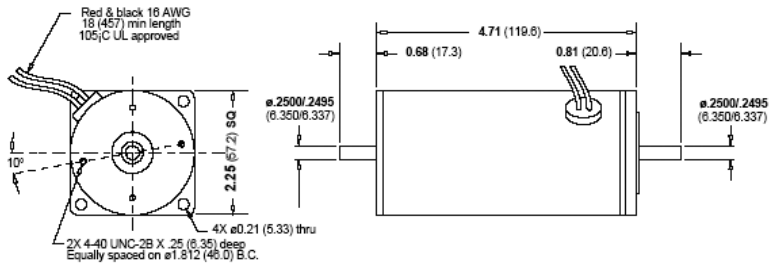
APPENDIX A/ *LAMPIRAN A*

D 24 Volt DC Motor Specifications

Standard (Single Shaft)



Inline (Double Shaft)



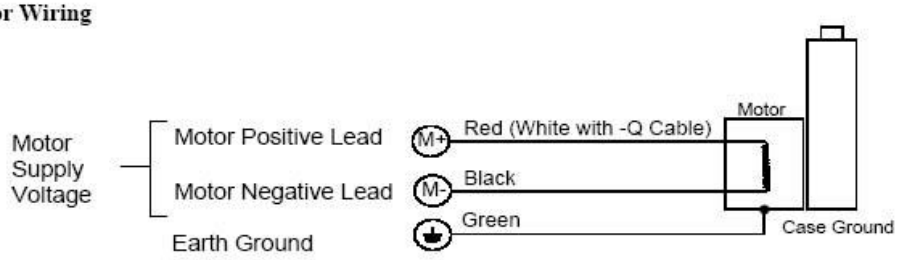
Electrical Data

Rated Voltage	V	24
Max. Current	A	4.5
Max. Operating Voltage	V	36
Armature Inductance	mH	2.0
Torque Constant , K_t	N-m/A	0.06
Back Emf Constant, K_b	V-s/rad	0.04
Armature resistance	Ohms	1.0

Mechanical Data

Continuous Stall Torque	N-m	1.44
No-load Speed at Rated Voltage	rad/s	600
No-Load Current	A	0.5
Motor Inertia	N-m-s^2/rad	5.8×10^{-4}
Motor Viscous Friction	N-m-s/rad	10^{-4}

Motor Wiring



APPENDIX B/ *LAMPIRAN B*

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-st}}{s}$		A delayed unit step function
$\frac{1 - e^{-st}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s + a}$	e^{-at}	Exponential decay
$\frac{1}{(s + a)^2}$	te^{-at}	
$\frac{2}{(s + a)^3}$	t^2e^{-at}	
$\frac{a}{s(s + a)}$	$1 - e^{-at}$	Exponential growth
$\frac{a}{s^2(s + a)}$	$t - \frac{(1 - e^{-at})}{a}$	
$\frac{a^2}{s(s + a)^2}$	$1 - e^{-at} - ate^{-at}$	
$\frac{s}{(s + a)^2}$	$(1 - at)e^{-at}$	
$\frac{1}{(s + a)(s + b)}$	$\frac{e^{-at} - e^{-bt}}{b - a}$	
$\frac{ab}{s(s + a)(s + b)}$	$1 - \frac{b}{b - a}e^{-at} + \frac{a}{b - a}e^{-bt}$	
$\frac{1}{(s + a)(s + b)(s + c)}$	$\frac{e^{-at}}{(b - a)(c - a)} + \frac{e^{-bt}}{(c - a)(a - b)} + \frac{e^{-ct}}{(a - c)(b - c)}$	
$\frac{\omega}{s^2 + \omega^2}$	$\sin \omega t$	Sine wave
$\frac{s}{s^2 + \omega^2}$	$\cos \omega t$	Cosine wave
$\frac{\omega}{(s + a)^2 + \omega^2}$	$e^{-at} \sin \omega t$	Damped sine wave
$\frac{s + a}{(s + a)^2 + \omega^2}$	$e^{-at} \cos \omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2 + \omega^2)}$	$1 - \cos \omega t$	
$\frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2}$	$\frac{\omega}{\sqrt{(1 - \zeta^2)}}e^{-\zeta\omega t} \sin [\omega\sqrt{(1 - \zeta^2)}t]$	
$\frac{\omega^2}{s(s^2 + 2\zeta\omega s + \omega^2)}$	$1 - \frac{1}{\sqrt{(1 - \zeta^2)}}e^{-\zeta\omega t} \sin [\omega\sqrt{(1 - \zeta^2)}t + \phi]$	
with $\zeta < 1$	with $\zeta = \cos \phi$	

APPENDIX C/ *LAMPIRAN C*

SECOND ORDER TIME DOMAIN SPECIFICATION
(*SPESIFIKASI DOMAIN MASA SISTEM TERTIB KEDUA*)

% Overshoot, $\%C_P = 100e^{-\left[\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right]}$
(%*Lanjakan Maksimum*)

Peak Time, *Masa puncak,* $t_p = \dfrac{\pi}{\omega_n\sqrt{1-\zeta^2}}$

Rise time, *Masa menaik,* $t_r = \dfrac{\pi - \cos^{-1}\zeta}{\omega_n\sqrt{1-\zeta^2}}$

Settling time, *Masa pengenapan,* $t_s = \dfrac{3}{\zeta\omega_n}$ (for 5% criteria/ kriteria 5%)

Settling time, *Masa pengenapan,* $t_s = \dfrac{5}{\zeta\omega_n}$ (for 2% criteria/kriteria 2%)

Error Steady State, *Ralat keadaan mantap,* $e_{ss} = \underset{s\to 0}{Lim}\dfrac{sR(s)}{1+G(s)H(s)}$

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